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GLOBAL FORM DEVIATION EVALUATION OF FREE-FORM SURFACE, USING COORDINATE MEASURING MACHINE

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ABSTRACT

In the modern manufacturing, free-form surface evaluation for confirmation the quality of produced as compare to the CAD model is crucial topic. A free-form surface is evaluated using contact and non-contact measuring instruments. The most common and old method of free-form surface evaluation is using contact coordinate measuring machine (CMM). To evaluate a surface using CMM, it is obvious that infinite sample point is required. But due to impractical practice samples are reduced to finite size. This finite sample size they can represent the surface to the extent level but not the whole surface. This paper investigates the novel method of free-form surface, in global form deviation evaluation of an adaptive sampling strategy using the dense sample cloud point. The dense sample cloud point gives true global form deviation. The measurement is made on 3 degree free-form surface and measure using contact probe. The proposed method is compared to the small sample size form deviation evaluation to validate its effectiveness and robustness.

KEYWORDS: Coordinate Measuring Machine, Form Deviation, Free-Form Surface & Sampling Strategy

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Original Article

INTRODUCTION

Free-form surfaces are surfaces, that don't have an axis of rotational symmetry and complex in shape [1]. The free-form surface has a wide application such as in die or mold manufacturing, plastic manufacturing, automobile, aerospace, and in advanced technology such as biomedical engineering etc.[2]. Free-form surfaces have properties like good ergonomics, aesthetic and functionality of the surface [3], due to this reason the application of free-form surface is increased from day to day. Evaluation the quality and accuracy of free-form surface is the current issue. The free-form surface is complex in nature, and it is difficult to measure using classical metrology measuring instruments due to their uncertainty problem. The free-form surface is evaluated using coordinate measuring machines (CMM), which the discretized data points are found in (XYZ) form from the machine coordinate frame or the part coordinate frame [4]. Sample size and location of the sample points are very important parameters in coordinate metrology of surface evaluation [5]. The discrete data of the free-form surface is acquired through non-contact (scanning) or contact (touch trigger probe). Form deviation evaluation using CMM by compared the actual measured surface to the design surface is one of the key issues in measurement. This form deviation evaluation could lead to the wrong result if we don't consider seriously. Most researchers evaluate the form deviation using the sampled discrete point which represents the local deviation of the surface. To find the global form deviation which is the maximum deviation of the surface the constructed surface from the discrete cloud point should convert into dense sample points. Works related to this objective are ElKott and Veldhuis [6], proposed sampling of the free-form surface based on iso-parametric sample lines, using the CAD model and

evaluate the form deviation from these sample points. Luca P. and Paul J. [7] Introduced adaptive sampling strategy based on shape decomposition principle, then based on the interest that reflects the variations they select the number of the samples according to the complexity of the shape and obtained optimal sample size and form deviation from the discrete sample points. Giovanni M. et al.[8] proposed sampling strategy based on Gaussian Process models, and the location is selected based on estimates obtained from a Gaussian Processes model, they investigate the profile error of the free-form surface, roundness of circular feature, and flatness of surfaces. Finally, they evaluate the form deviation of each shape for confirmation using the discrete sample points. Małgorzata P. [9] Free-form surface geometric errors are determined at each point, as normal deviations of measurement points from the nominal surface of the CAD model.

This paper introduced a method of global form deviation evaluation using the dense sample point of the constructed surface. For validation of our method we compare the result with the common method of discrete based form deviation evaluation.

TOOLS USED FOR EVALUATION OF NURBS FREE-FORM

NURBS FREE-FORM SURFACE REPRESENTATION

In this work we have been used NURBS surface as described on [10] to investigate the proposed sampling strategy, NURBS models are developed in Rhinocreo4 (student version). For a given control point, base function and weight of the control point, the mathematical representation of NURBS free-form surface is

$$S(u,v) = \sum_{i=0}^{n}\sum_{j=0}^{m} R_{ij}\,(u,v)P_{ij}\ 0 < u,v < 1 \tag{1}$$

$$R_{ij}\,(u,v) = \frac{N_{i,p}(u)N_{j,q}(v)w_{i,j}}{\sum_{k=0}^{n}\sum_{i=0}^{m} N_{k,p}(u)N_{i,q}(v)w_{k,i}} \tag{2}$$

Where: $N_{i,p}(u)$, $N_{i,q}(v)$ are base functions along u and v,$P_{i,j}$ is control points, $W_{i,j}$, $W_{k,i}$ are weight of each control points along u and v.

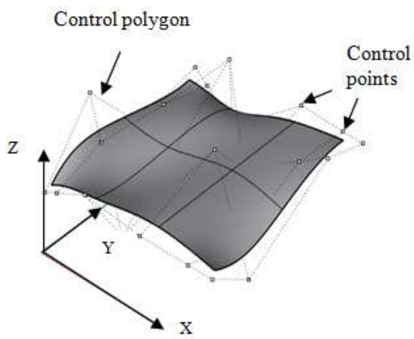

Figure 1: NURBS Free-form Surface Representation in Rhino creo4 (Student Version)

EQUI-PARAMETRIC SAMPLING STRATEGY

In equi-parametric sampling strategy, sample points are equally distributed in the *u-v* space of the free-form surface as shown in Figure.2 below as used on the paper [11]. As compared to the other sampling methods it is the simplest and easily implemented on NURBS surfaces. Equi-parametric sampling is under the category of blind sampling strategy, and insensitive to surface complexities such as sharp curvature changes and unequal surface-patch sizes.

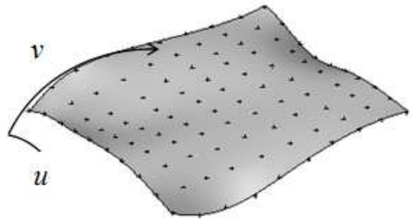

Figure 2: The Concept of Equi-Parametric Sampling Strategy Distribution of Sample Point

DENSE CLOUD POINT OF FREE-FORM SURFACE FROM CONSTRUCTED SURFACE

After sample data point are collected from the actual surface using CMM, the discrete data point should fit to best approximate of the surface, in this work fitting did by least square method 2.5D the best fit [12]. From the sample points the surface mesh is constructed, and smoothing applied to approximate the constructed surface. The detail processes meshes construction and dense cloud point generation is explained in Figure.3 and Figure. 4 below.

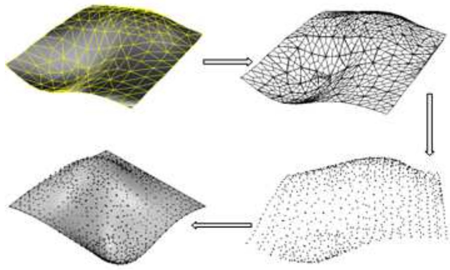

Figure 3: Steps Dense Cloud Point Generation from Constructed Surface

FREE-FORM SURFACE FORMS DEVIATION CALCULATION AND INSPECTION UNCERTAINTY ANALYSIS

Form deviation of the free form surface is measured, by comparing the design surface to the measured or actual discrete sample points. In CMM form evaluation, before we start the measurement, the CMM should calibrate to reduce the measurement error. In this paper, the uncertainty of measurement is evaluated using calibrated artifacts of round ball (master ball) and slip gauges (ISO 15530-3). And the average global form deviation, is our true form deviation of the surface. Mathematically defined in such a way,

$$M(x) = P(x) + d \quad (x) \tag{3}$$

$$d_{avg}(x) = \frac{\sum_{i=0}^{n} \hat{n}[M(x) - P(x)]}{n} \tag{4}$$

Where: *M(x)* is the actual measured sample points, *P(x)* is the nominal design surface, $d_{avg}(x)$is the average global form deviation, $\hat{n}$ is the normal vector from nominal to the actual, *x* is form variable, *n* is a number of the measurement.

After samples are collected from the surface randomly, an N(0.005,0.01) noise is added to each sample points and result of the application is denoted as actual point set [12]. To check the robustness the measurement Type A uncertainty of both method is analyzed. Thus, a statistical analysis of *n* repetitive measurement data using both methods, the variance of the inspecting value is computed as the method used in [13]:

$$s^2(d) = \frac{1}{n-1}\sum_1^n (d_i - d_{avg}(x))^2 \tag{5}$$

$$u(d) = \sqrt{\frac{s^2(d)}{n}} \tag{6}$$

METHODOLOGY OF THE EXPERIMENT

To evaluate the form deviation of the free-form surface, NURBS type model of degree three is designed. To verify our method we used Aluminium alloy (Al-6061) of the surface of 100mmX100mm in dimension. An NC code is generated and machined on CNC VM machine. The machined surfaces are subjected to measurement using CMM with 2mm ball contact probe based on the method of the equi-parametric sampling strategy. The step followed to accomplish this work is explained below and on Figure. 4.

- NURB free-form surface model is designed using Rhino ceros Figure. 1.
- NC code generated using Master cam X9 and surfaces are machined by the vertical milling machine.
- N number of discrete sample points are distributed using equi-parametric sampling strategy.
- Discrete data are collected using the coordinate measuring machine from the free-form surface.
- Registration of cloud point to the design surface.
- Measure the deviation between the cloud point and actual surface.
- Convert the measured discrete point in step 4 into dense cloud point using step explained in Figure. 3.
- Measure the deviation between the dense cloud point and actual surface.
- Compare step 6 and 8 to validate the results.

EXPERMENTAL RESULT

After the samples are distributed on the model, the surface measured using MITUTOYO: a model of Crysta-plus M544 CMM at the protected environmental temperature of 20±2^{0}C, based on the standard the accuracy of CMM. The maximum permissible error position of the machine is E=(3.5 +4.5L/1000)µm, and the samples are distributed based on the above-mentioned methods. The measurement is repeated 10 times, to minimize the error due to repeatability. The surface is machined using 3-axis vertical milling CNC machine model of VML800, spindle speed of 2000rpm with accuracy ±0.005mm. The assumed tolerance is ±0.5mm.

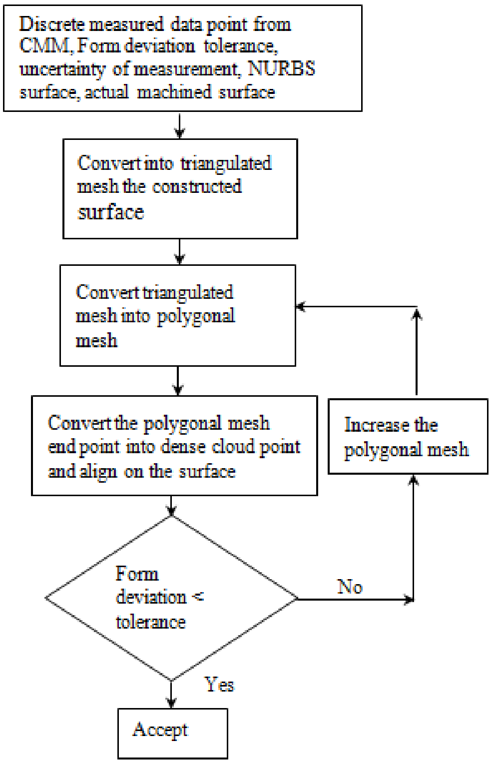

Figure 4: Flowchart of Dense Cloud Point Generation from the Constructed Surface

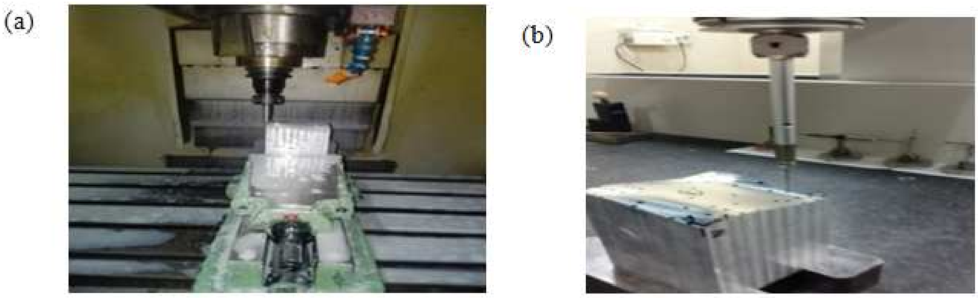

Figure 5(a): CNC Machining of Free-Form Surface (b) CMM Measurement

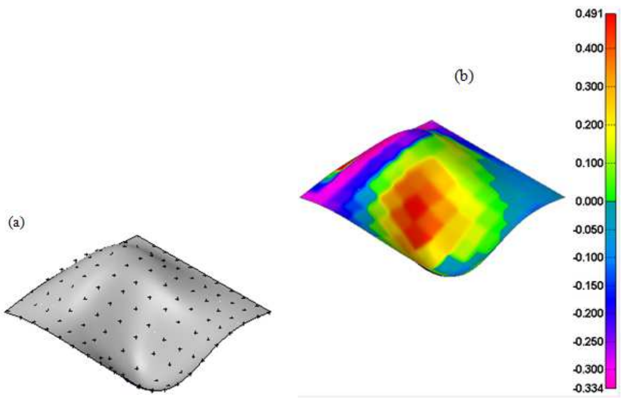

Figure 6(a): Equi-Parametric Sample Distribution 11ux11v (b) Coresponding Local Form Deviation

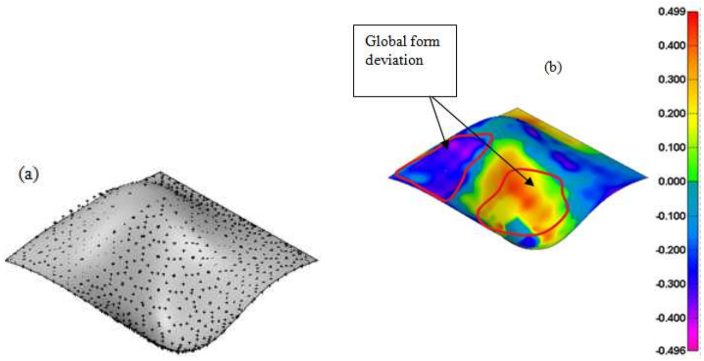

Figure 7 (a): Dense Sample Distribution (b) Coresponding Global Form Deviation

Table 1: Comparison of the Small Size Sample and Dense Cloud Point Deviation Analysis

Sample Distribution	Small Size Sample Points	Dense Cloud Sample Points
Tolerance(mm)	±0.5	±0.5
# sample Points	121	655
Avg. form deviation(mm)	0.490	0.496
Std. Dev.	0.071	0.081
Type A uncertainty	0.027	0.029
Pts within +/-(1 * StdDev)	91 (75%)	411 (62%)
Pts within +/-(2 * StdDev)	117 (96%)	637 (97%)
Pts within +/-(3 * StdDev)	118 (97%)	655 (100%)
Pts within +/-(6 * StdDev)	121 (100%)	655 (100%)
Surface Out of Tolerance	0.00%	0.00%

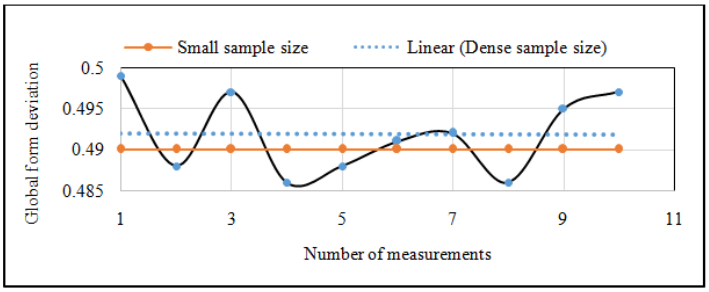

Figure 8: The Dense Sample Point Global Form Deviation Distribution for Repeated Measurement

CONCLUSIONS

From the above form deviation distribution Figure. 7(b) the map diagram represents the maximum global form deviation of the free-form surface as compared to the map form deviation distribution of Figure. 6(b) for the same surface. The global deviation of the surface 0.491mm on Figure. 6(b) is not the maximum global form deviation of the surface, the true global deviation is the deviation from the dense cloud point i.e 0.499mm Figure. 7(b). Even though the global deviation of the dense sample point is greater than the small sample size one, the true global deviation is the dense sample points form deviation. Above all no need to measure the dense sample points, it is created from the constructed surface mesh. From Table I the uncertainty Type A of the dense sample point deviation is greater than the small sample size distribution due increase in sample points. The method is robust from the statistical result Type A uncertainty of the dense sample points is equal to the small sample size uncertainty and effective the average global form deviation of the dense sample point is close to the small sample size as shown on Figure. 8.

REFERENCES

1. *X. Wen, D. Wang, Fangli1, and Y. Zhao, "Sampling strategy for free-form surface inspection using coordinate measuring machines," Applied Mechanics and Materials, vol. 532, pp. 106-112, 2014.*
2. *G. Rajamohan, M. S. Shunmugam, and G. L. Samuel, "Practical Measurement Strategies for Verification of Freeform Surfaces using Coordinate Measuring Machines," Metrology and Measurement Systems, vol. Xviii, no. 2, pp. 209-222, 2011.*
3. *E. Savio, L. De Chiffre, and R. Schmitt, "Metrology of freeform shaped parts," Annals of the CIRP, vol. 56, no. 2, pp. 810-835, 2007.*
4. *M. Poniatowska, "Deviation model-based method of planning accuracy inspection of free-form surfaces using CMMs," Measurement, vol. 45, pp. 927–937, 2012.*
5. *Y. Xu, and Z. Li, "Method for Determining the Probing Points for Efficient Measurement of Freeform Surface," International Journal of Mechanical, Aerospace, Industrial, Mechatronic and Manufacturing Engineering, vol. 2, no. 2, pp. 230-235, 2008.*
6. *D. F. ElKott, S. C. Veldhuis, "Isoparametric line sampling for the inspection planning of sculptured surfaces," Computer-Aided Design, vol. 37, pp. 189–200, 2005.*
7. *L. Pagania, P. J. Scotta, "A sampling strategy based on B-wavelets decomposition," Procedia CIRP, vol. 43, pp. 29-34, 2016.*
8. *R. Ascionea, G. Moronia, W. Polinib, and D. Romanoc, "Adaptive inspection plans in coordinate metrology based on Gaussian Process models," Procedia CIRP, vol. 10, pp. 148-154, 2013.*
9. *M. Poniatowska, "Discrete Geometric Deviations of Free-form Surfaces as a Spatial Process," Advances in Manufacturing Science and Technology, vol. 34, no. 4, pp. 73-85, 2010.*
10. *L. Piegl., and W. Tiller., "The NURBS Book," Springer, Berlin, Germany, 2:641, 1997.*
11. *D. F. Elkott, H. A. Elmaraghy and W. H. Elmaraghy, "Automatic sampling for CMM inspection planning of free-form surfaces," International Journal of Production Research, vol. 40, no. 11, pp. 2653-2676, 2002.*
12. *Sreeram Reddy Gundeti et al., The Comparison of Deviations of Freeform Surfaces using Re-Engineering By Non-Contact Scanners, International Journal of Mechanical and Production Engineering Research and Development (IJMPERD), Volume 7, Issue 2, March - April 2017, pp. 127-134*
13. *S. Oliver, and S. Marie, "Surface from Scattered Points: A Brief Survey of Recent Developments," Unpublished.*
14. *H. Liu, Y. Wang, X. Huang and L. Xue, "Isoplanar-based adaptive sampling for model-unknown sculptured surface coordinate metrology using non-contact probe," International Journal of Advanced Manufacturing Technology, vol. 64, pp. 1695–1707, 2013.*
15. *M. Yu, Y. Zhang, Y. Li and D. Zhang, "Adaptive sampling method for inspection planning on CMM for free-form surfaces," International Journal of Advanced Manufacturing Technology, vol. 67, pp. 1967–1975, 2013.*